AD-A114 421 NAVAL BIODYNAMICS LAB NEW ORLEANS LA F/G 5/10
IMPLICATIONS OF DUAL-TASK PERFORMANCE VARIABLES FOR DESIGN OF G--ETC(U)
NOV 81 M PATSFALL
UNCLASSIFIED NBDL-81R014 NL

1 of 1
AD A
114421

END
DATE
FILMED
6-82
DTIC

30

NBDL - 81R014

IMPLICATIONS OF DUAL-TASK PERFORMANCE VARIABLES FOR DESIGN OF GENERIC WORKSTATIONS: LITERATURE REVIEW

MICHAEL PATSFALL

NOVEMBER 1981

NAVAL BIODYNAMICS LABORATORY
New Orleans, Louisiana

NBDL - 81R014

IMPLICATIONS OF DUAL-TASK PERFORMANCE VARIABLES FOR DESIGN OF GENERIC WORKSTATIONS: LITERATURE REVIEW

MICHAEL PATSFALL

NOVEMBER 1981

Bureau of Medicine and Surgery
Work Unit No. MF58.524.02E-0002

Approved by

Channing L. Ewing, M. D.
Chief Scientist

Released by

Captain J. E. Wenger MC USN
Commanding Officer

Naval Biodynamics Laboratory
Box 29407
New Orleans, LA 70189

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: 81R014	2. GOVT ACCESSION NO.: AD AD-A114 411
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle): Implications of Dual-Task Performance Variables for Design of Generic Workstations: Literature Review	5. TYPE OF REPORT & PERIOD COVERED: Research Report
	6. PERFORMING ORG. REPORT NUMBER: NBDL-81R014
7. AUTHOR(s): Michael Patsfall	8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Naval Biodynamics Laboratory, Box 29407, New Orleans, LA 70189	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: MF58.524.02E-0002
11. CONTROLLING OFFICE NAME AND ADDRESS: Naval Medical Research and Development Command, Bethesda, MD 20014	12. REPORT DATE: November 1981
	13. NUMBER OF PAGES: 23
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	15. SECURITY CLASS. (of this report): UNCLASSIFIED
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Information Processing, Dual Task, Time Sharing, Generic Workstation

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This is a review of dual-task performance findings related to design of a generic workstation performance test. The effect of multiple inputs/outputs on performance is best explained in terms of overlap of input/output requirements on mental resources. Mental resources can be usefully categorized by sensory modality of input/output, stages of mental processing, and laterality of brain function. Inputs/outputs which have overlapping requirements in one of these categories generally interfere with each other. There does not appear to be a general time-sharing ability possessed to different degrees by different people

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

S/N 0102-014-6601

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

SUMMARY PAGE

THE PROBLEM

Most jobs involve multiple sources of information, several mental processes, and more than one type of response. It is widely acknowledged that performance on simple personnel tests involving single inputs, mental processes, and outputs is only weakly related to performance on real jobs. Nonetheless, a method is needed to test performance in realistic tasks. A complex but controlled performance test, the "generic workstation", is proposed as a realistic alternative to simple tests. Development of a generic workstation presupposes knowledge of how the multiple inputs and outputs of a complex workstation draw on the mental resources of an operator. This review summarizes the state of knowledge about performance of complex work.

FINDINGS

The effect of multiple inputs/outputs on performance is best explained in terms of overlap of the input/output requirements on mental resources. Mental resources can be usefully categorized by sensory modality of input/output, stages of mental processing, and laterality of brain function. Inputs/outputs which have overlapping requirements in one of these categories generally interfere with each other. There does not appear to be a general time-sharing ability possessed to different degrees by different people.

RECOMMENDATIONS

Design a generic workstation in such a manner that multiple-task interference can be scientifically controlled using the principles reviewed herein.

ACKNOWLEDGEMENTS

The author would like to acknowledge the contributions to this paper by LCDR Robert Carter and CDR Richard Shannon of the Naval Biodynamics Laboratory who were, respectively, supervisor and principal investigator of the work.

The work was funded by the Naval Medical Research and Development Command and by the Biological Sciences Division of the Office of Naval Research.

TABLE OF CONTENTS

INTRODUCTION

Optimal human performance in a tactical combat information center (CIC) can be conceptualized as an interaction between the capabilities and qualities of the human operator and the characteristics of the machine system. In a system that requires attention to multiple sources of information and many different responses, it can be expected that overall performance will depend on the congruence of the machine demands and the processing and response capabilities of the operator. Consequently, the development of a generic work-station to test such complex performance presupposes knowledge of functional relationships between the processing demands of a task and human qualities that affect performance. Similarly, the development and assessment of a battery of performance evaluation tests for environmental research can be accomplished in terms of the qualities of the tests and how they might be combined to reflect an analog to complex performance in a natural setting, i.e., a CIC.

The use of performance evaluation tests to predict complex task performance can be conceptualized as a three-part model, consisting of: (1) the tests and their functional demands, 2) the structure of human information processing resources, and 3) subject-task interaction variables. The demands of any given test can be described in terms of either the task elements required to perform on the test, or more typically, in terms of the worker-oriented abilities that are needed to perform on the test. McCormick and his colleagues have established relationships based on expert judgment between job elements and human abilities required by the job (McCormick, Jeanneret, & Mecham, 1972; Marguardt & McCormick, 1972). This report will side step the issues of testing simple abilities one at a time. Instead it will focus on problems of doing several things at the same time. In such situations the subjects' abilities interact with the demands of tasks. Subject-task interaction variables include environmental, individual, and contingency variables that constitute constraints on the system set by a specific combination of tasks and individuals. The potential interactions among such subject-task variables and the processing resources are of particcular interest in the multiple task situation of a generic workstation. Subject-task interactions might be expected to occur and influence performance in unpredictable ways in multiple task situations. The observable performance outcomes of subject-task interactions give us clues about the structure of human information processing resources.

The strongest empirical base linking the human processing structure and the subject task variables is found in the dual-task literature and is comprised of a number of closely related paradigms. The studies reviewed here could be classified by the experimental paradigm employed. One common paradigm has been to pair a primary continuous task, generally tracking, with another continuous or discrete task. The other common paradigm has been to pair a discrete task, typically a reaction time (RT) measure, with a continuous or discrete task. These paradigms include the cases of pairing tasks with themselves. This framework will be reexamined in a later section.

The effects of the known subject-task variables are most meaningful in terms of how they are processed in the task situation. Therefore this paper will begin with a brief description of the model of the structure of process-

ing resources employed as a framework to view the basic findings. This discussion will be followed by the empirical findings on the major variables affecting dual-task performance, given in terms of the processing model. A supplemental summary of the major findings is given in Table 1. This table generally includes only the experimental studies utilizing a dual-task paradigm. Review papers and supporting studies not considered to fit within the dual-task paradigm are generally not included in this table. Finally, summary recommendations regarding the relation of the factors to the implementation of a generic workstation will be offered.

THE STRUCTURE OF PROCESSING RESOURCES AND TASK OVERLAP

Processing Resources

The model of processing structure in the present review defines the structure of resources in terms of three dimensions; (a) modes of input and output, (b) stages of processing, and (c) codes of central processing. This multiple capacity model of attention holds that there are various types or pools of resources, each having some semi-independent capacity, which act to support a number of structure-specific behaviors (Wickens, Mountford, & Schreiner, 1981).

Modes of input and output refer to which perceptual system encodes the information necessary for performance and what response system is utilized for making a response. Unfortunately, stages of processing are not well understood and many models have been developed. This lack of understanding presents a problem, as inadequate specification will lead to misprediction of interference among dual-task components. In one good analysis of processing demands, Kerr (1973) categorized mental operations into general classes of encoding, multiple input, rehearsal, transformation, and responding. Although this typology is comprehensive and not overly complicated it lacks some necessary specificity. As an example of this problem, North's (1977) interpretation of the interference effects due to cognitive transformations required a post hoc differentiation of the types of transforming required in tracking and a digit classification task. One might include the further specification of short and long-term memory type, decision-making and choice, as well as the distinction between response selection and execution. The important point is that tasks will vary in the types of processing required and the degree to which they load on different stages. This will affect how well various combinations of tasks can be performed although specification of effects may not be easily made (Navon & Gopher, 1979).

The last dimension of processing resources, the code of central processing, refers to the lateralization of function by hemispheres of the brain (Kimura, 1969; Kinsbourne, 1975). One emerging model used to explain lateralization effects has moved from a computer-based model of simple differentiation to one of a functional space (Kinsbourne & Hicks, 1978). In this model interference between concurrently active inputs is predicted from functional and structural characteristics, such as the type of material being processed, or the relation between response modes.

Task Overlap

The most salient factor in dual-task performance is probably the degree to which two or more tasks overlap with regard to their individual demands on the dimensions of processing resources (Wickens et al., 1981; North, 1977; Navon & Gopher, 1979). Such overlap of demands on the processing resources is generally addressed in terms of performance decrement on one or both of the subtasks, but performance enhancement has been noted under certain conditions (e.g., Pomerantz, Sager, & Stoever, 1977). Such enhancement effects are mostly found within the perceptual area and are probably due to stimulus summation. Multiple-task interference can occur at any point in processing, and any task set must be examined for degree of overlap for each division of processing resources. For purposes of this review, processing resources will be divided in terms of a) modality of input/output, b) stages of processing, and c) laterality of brain function.

Task overlap and modality of input/output. Wickens et al. (1981) have recently demonstrated that, with few exceptions, task pairs in which one input mode is auditory and the other is visual, are co-performed better than tasks which require input in the same modality. Treisman and Davies (1973) had reached the same conclusion earlier regarding dual-tasks of monitoring in visual and/or auditory modes. This effect for greater efficiency of processing of different inputs over same inputs is highly reliable, but when other processing dimensions enter in, exceptions may occur. For example, Wickens et al. (1981) found that shared discrete-response visual tasks were slightly more efficient than pairs composed of the auditory and visual subtasks. More typically, however, McLeod (1977) found that a choice reaction time task using manual responses, paired with a tracking task interfered more with the tracking task than when the reaction time task employed a verbal response. Since the tracking response was manually performed, the results support the idea of interference based on the similarity of input/output mode. Shaffer (1975) has noted that manual tasks (such as typing) can be performed at high levels using visual input while doing a verbal task. Manipulating the second task suggests that interference is greater between two tasks when response types are formally similar. There is, for example, relatively more difficulty in typing from an auditory rather than visual source while verbally shadowing or reading aloud.

In another instance, a tracking task was paired with a continuous digit substitution task, using either a vocal or keyboard response. For one of several dependent measures, the density of errors, there was a significant decrement on digit processing. As would be expected, there was less decrement in the vocal mode than in the keyboard mode, even when the keyboard was laid out for high response compatability, and subjects were given practice on the keyboard task (Harris, Owens & North, 1978). There is data to suggest that under the right conditions the visual and auditory modes can process verbal information independently with little interference. For example, Rollins and Hendricks (1980) employed tasks requiring simultaneous processing of auditory and visual messages. Subjects were able to detect both target words and category targets presented visually, but were less able to detect target words presented auditorily and rhyme words presented visually. This suggests processing semantic properties, but not acoustic properties, of words when presented in the visual mode is independent of simultaneous processing in the

auditory mode. Visual and auditory modalities can process verbal material without major interference, at a level that allows some degree of semantic analysis of words in each message. This does not seem to be true when acoustic properties of the visually presented task are presented in concurrence with the auditory task.

The effects of input and output mode are somewhat complicated by the influence of hemispheric function. Brooks (1968) showed performance was better when the input processing of a task was in a mode dissimilar to the response modality. Verbal responses interfered less with recall of a graphic linear pattern than spatial responses, while spatial responses interfered less with recall of semantic material than did verbal responses.

In general, encoding inputs in tasks, such as in pure monitoring tasks, requires minimal processing effort in a dual task situation (Kerr, 1973; Norman & Bobrow, 1975), but the implication of subsequent processes (memory, response initiation, etc.) seems to alter the monitoring capability. Once response initiation, selection, and execution becomes necessary, Norman and Bobrow (1975) note there seems to be a shift in the criterion for making a response to signals in a contralateral channel, thus making signals there seemingly less detectable. Ostry, Moray, and Marks (1976) have demonstrated that monitoring of two streams of information in parallel is a relatively simple task until a target requiring further processing arrives, which seems to 'lock up' or attenuate the mechanism until the processing is complete.

In general, then, the effects of input/output mode are toward greater decrements when shared tasks also share the same input and/or output channels. The nature of the stimuli, however, plays a role in the relative processing efficiency and part of this may be due to lateralization of the process handling the stimuli type.

Task Overlap and Stages of Processing. Differential demands placed on the various stages of processing for the subtasks will affect the amount of interference between the subtasks and consequently the overall performance. North (1977) and Wickens et al. (1981) found greater relative decrements in performance on a dual compensatory tracking task paired with itself than when the tracking task was paired with visual tasks requiring discrete responses. The effect was ostensibly due to greater demands on the stages of response selection and execution of manual control in the twin tracking task, while the discrete response subtasks in the heterogeneous pairing drew more on stages of perceptual encoding and central processing, thus spliting the total processing demands over different resources. Similarly, Wickens and Kessel (1980) found differences in the effects of loading tasks (a tracking task or a mental computation task) on subjects' ability to either manually control a failure-detection pilot simulation, or monitor an auto-pilot system. The tracking loading task significantly disrupted the manual failure-detection task, but not the auto-pilot monitoring task. The computation task, on the other hand, disrupted the auto-pilot and monitoring task, but not the manual failure-detection task. This pattern is consistent with the idea that the auto-pilot monitoring task relies highly on perceptual and central processing, while the manual failure-detection task relies more heavily on a response related reservoir requiring a lesser amount of central processing. The loading tasks themselves split even more in that regard since the mental computation

task seems to be nearly all central processing, while the tracking task is largely a response oriented task. Thus, the loading tasks differentially interfere with the primary tasks with which they share most of their processing requirements. It is noteworthy that, in this experiment and a similar one (Wickens & Kessel, 1979), the manual failure-detection mode of participation resulted in more superior performance than the auto-pilot mode (where input information was essentially all visual). The manual mode provided proprioceptive information (by the use of a joystick) about the control inputs immediately delivered to the system. Therefore, it appears that manual tracking is a heavily response loaded task, which is difficult to perform with other response oriented tasks. Monitoring, however, seems to be more centrally controlled and can be shared with tracking.

While tracking and reaction time type measures logically load on different stages of processing to some degree, they are not independent in that regard. Damos and Wickens (1977) found tracking decreased when shared with a choice reaction time task. Long (1976), however, had to pool the data from two experiments with paired reaction time tasks to show significant interference.

Short term memory requirements on one or both subtasks in a dual-task situation are usually disruptive of performance (North, 1977; Wickens & Kessel, 1980; Welford, 1978). Tasks requiring storage, retrieval, and transformation of information (such as digit cancellation or delayed digit cancellation) cause performance decrements in conjunction with similar tasks, even when the second task had no significant memory component. On the other hand, in a series of experiments, Logan (1978) paired a character-classification task with a short term memory table and manipulated the stage of processing affected. In this case, memory load was not found to interact with stages of encoding, decision, or response-selection. In addition, for the remaining stage comparison, only one of three measures (target set size) was significant. It was concluded that the demands of those stages for the classification task were basically automatic, which is contrary to the conclusions reached by most authors.

Shulman and Greenberg (1971) paired a short-term memory task with a comparative judgment task involving alphabetic material and a perceptual recognition task involving numerals. When the dependent measure was recognition rate or reaction time without error, performance on the perceptual tasks was inversely related to memory load. Henderson's (1975) claim that verbal output interferes with cognitive tasks appears to be contrary to the aforementioned idea. He found that a shadowing task, repeating sentences, interfered with performance on a task of unscrambling sets of visually presented words to form sentences. However, shadowing probably involves at least a moderate degree of central processing. In addition, it may not be the response portion of the shadowing that is interfering with the congnitive task. While Allport, Antonis, and Reynolds (1972) found memorization could be shared with speech shadowing, the decrement was considerably larger for verbal, as opposed to pictorial, material.

The further specification of the relative demands of different stages, given specific conditions, is a desirable step in the planning of complex environments. Wickens (1976) showed, in one instance at least, that dual-task performance decrements as units of attention are more severe in output than input stages. The negative effects on a tracking task were greater for the addition of a constant force application task than for a signal detecion task,

and seemed to involve changes in response bias and processing noise (i.e., from two proprioceptive sources vs. one visual and one proprioceptive). Similar to this was the finding of Trumbo and Milone (1971) who presented a tracking task in conjunction with a serial learning task, where stages of encoding, retaining, or recall could be differentially paired with the tracking operation. Decrements in tracking were found to be greatest during recall, next largest in retention, and least in encoding. Tracking did not interfere with processing of the secondary task. In the first experiment, the word stimuli were represented visually, while in the second, auditory presentation was used. This evidence supports the notion that response selection and/or execution, which are required at recall, are more demanding or more limited in capacity, than the processing or encoding of stimuli. In this case, even though encoding was the least affected stage of processing, there was a reliable effect due to that stage.

A few studies have looked at the relations among specific verbal-oriented subtasks, and their power to predict general verbal ability. Lansman (1978) reports studies attempting to predict verbal ability by single and dual task performance using a memory task paired with a type of grammatical reasoning. Dual and single task performance should not be highly correlated if subjects differ in their attentional capacity or efficiency of processing either task. Single and dual task performances were, in fact, highly correlated and the patterns of correlations between the two types of tasks and criterion measures suggested performance in dual tasks was no better than performance in single tasks in predicting verbal ability.

Hunt, Lansman, and Wright (1979) found that the performance of a psychomotor task (e.g., shooting a moving target) interfered with a primary task of comprehending a verbal message, while changes in the difficulty of the message had no detremental effect on performance of either of the two psychomotor tasks. The authors noted, however, that the subjects' lack of practice on the secondary task may have been influential. With pretraining, automation on the motor task may have nullified the detrimental effect on verbal comprehension. It is unfortunate that this finding was not less equivocal, since the pairing of a verbal comprehension task with a psychomotor task may be highly relevant to performance in a CIC.

The type of mental transformation, in terms of the stage of mental processing, is important in producing an effect. In a task pair composed of compensatory tracking and digit classification, North (1977) found no interference. This was, presumably, since the transforming in the former subtask, differentiation and integration to convert continuous error indication into corrective movements, required different resources than for the latter subtask. There, the digit classification involved an interactive, discrete, and dimensional categorization of similarities and differences. While tracking paired with any of these keyboard response tasks showed the least interference, two tracking tasks interferred less with each other than two keyboard tasks paired with themselves. In that case, if one of the keyboard tasks required significant memory (e.g., as in delayed digit classification), interference was greatest. Wickens and Kessels' (1980) conclusions are supported by this in that their findings are explained by suggesting that perceptual encoding and memory may tend to be somewhat more dependent on shared reservoirs whereas the so-called response reservoir is relatively independent of the former.

They found considerably more interference on dual tasks within these two hypothetical reservoir groupings than dual-tasks with loadings split between them.

It is noteworthy that a number of the difficulty-performance tradeoffs and insensitivities are not symmetrical. That is, whether or not a tradeoff is exhibited depends on which task is being manipulated. For example, when tracking task difficulty is manipulated when shared with an encoding task, there is typically no effect on performance of the latter task (Isreal, Chesney, Wickens, & Donchin, 1980; Wickens & Kessel, 1980). However, when encoding difficulty is varied, an effect on tracking performance has been demonstrated. Briggs, Peters, and Fisher (1972) and Johnston, Greenberg, Fisher, and Martin (1970) got mixed results showing difficulty in sensitivity in one case, but not in another. Likewise, it appears that there is some asymmetry of effect regarding the pairing of tracking and central processing tasks. Kantowitz and Knight (1976) varied tracking difficulty paired with a digit-naming task and found a significant tradeoff, as did Zeitlin and Finkelman (1975), manipulating tracking in conjunction with a shadowing task requiring short term recall of digits. However, tracking performance was not substantially different under single or dual-task conditions (including when tracking was also paired with a random digit generation task). McLeod (1977) found manipulations of a mental arithmetic task had no effect on tracking performance. While in the use of tracking and encoding, the asymmetry of the difficulty performance tradeoff is clear; in the case of tracking/central processing pairs, it is not, and requires further investigation.

Task Overlap and Laterality of Brain Function. The code of central processing has served as an explanation for a number of findings in dual-task performance. Most recently Wickens et al. (1981) explained the ordering of interference effects among four task pair combinations by the degree of spatial/visual or verbal/analytic requirements in the task pairs. Each task paired with an auditory running memory task showed less decrement with less verbal/analytic and more visual/spatial processing required (i.e., number classification, line judgment, and tracking, respectively). It should be noted that this was true even though classification and judgment tasks had similar input and response-type relationships. The more the requirements of two simultaneously performed tasks are similarly lateralized, the more interference should be expected. Damos and Smist (1980) have implicated the degree of lateralization of function as a source of individual difference (measured on certain psychomotor tests) that is associated with different response strategies in executing dual-tasks. The nature of these strategies will be elaborated later, however, it should be noted that while the evidence for these individual differences is strong, the association to hemispheric lateralization needs further substantiation.

Wickens et al. (1981) convincingly showed that performance is superior when the hemisphere involved in central processing of the subtask coincides with the hemisphere controlling response (e.g., left hemisphere processing with a right-hand response). In addition, Kinsbourne and Hicks (1978) have summarized evidence regarding interference in response systems (e.g., between limbs and they found decreasing efficacy on dual tasks requiring motor responses as the response demands changed from limbs paired diagonally, to paired ipsilaterally, and then to mirror-image paired. Interference also occurs between voice-manual (either verbal or simply vocal) response pairs.

Typically, greater interference is found between voice and right hand responses paired in a dual-task than between voice and left hand responses. Since verbal processing is nearly always left hemisphere dominant, which controls the right side motor responses, this proximity in the hemispheric functional space can be expected to interfere more than left hemisphere process/left hand response.

Perceptual interference has been noted as well, such that different types of stimuli in paired subtasks are processed more accurately than similar stimuli types, e.g., words and tones (Kinsbourne & Hicks, 1978). In an extension of this finding, Teng (1980) demonstrated that performance on a shadowing task with mixed or same type input material (tones and/or digits) was better for the mixed, rather than same type of input. There was a significant right ear advantage for digits and a left ear advantage with tones for pairings of same material type. There was, however, no significant ear advantage when the data from the two mixed-type pairing tests (i.e., digit left, tone right, and vice versa) was combined. Teng (1980) concludes from this and other supporting evidence that the advantage of the contralateral over ipsilateral input increases as the input from the two ears compete for the same type of processing.

Briggs (1975) found a significant interaction between handedness in response and secondary task condition (verbal vs manual). He observed the right hand making significantly more errors in the verbal condition, while the left hand made nonsignificantly fewer errors in the manual condition. This would be expected from the previous findings on lateralization.

Hellige and Cox (1976) found that the effect of a concurrent memory task on recognition of spatial forms was significant when the forms were presented to the right visual field. When the stimuli were words, the effect was seen for both visual fields. Both of these effects, however, were in the direction of facilitated performance when the memory load was low or moderate. Performance decrements were seen only when memory load was high. The performance facilitation at low memory was apparently due to a general activation of the hemisphere involved in the processing of the primary task. Some recent evidence suggests, however, that even relatively simple processing operations, such as mental computation, may be comprised of component processes which call upon different hemispheric resources. Arithmetic subtraction is basically left hemisphere controlled, but a component process, judging which number is larger, seems to be right hemisphere controlled (Katz, 1980). Clearer understanding of lateralization effects may require an anlysis of the specific demands in any given operation.

TIME-SHARING

The contemporary literature suggests that time-sharing does not exist as a general, transituational ability (Navon and Gopher, 1979; Jennings & Chiles 1977). For example, Sverko (1977) factor analyzed the correlations among single and dual-task performances for 4 dissimilar tasks and all possible pairings. The analysis revealed only 4 factors all of which were task-specific; there was no general time-sharing factor found. In addition, the correlations of performance decrement scores across dual-tasks (done with the constraint that the correlated tasks had no common subtasks) were small and insignificant. However, changes in complex performance have been demon-

strated for specific task sets which may be generalizable to classes of task combinations. Jennings and Chiles (1977) found a time-sharing factor for monitoring, that is, rapid shifting of attention from active subtasks (e.g., mental arithmetic) to monitoring subtasks. There was no factor which crossed over the task sets as a general complex performance factor. The main factor of interest revealed by their analysis had high loadings on two different visual monitoring tasks when each was paired with other tasks but not singly. No other tasks done in concurrence loaded on this factor, and so it seems to be quite specific to a class of tasks.

Hawkins, Rodriguez, and Reicher (1979) found greater correlations among time-sharing conditions when there were more common task demands. These authors conclude time-sharing to be, at least within the dual reaction time paradigm, composed of a number of poorly correlated, task specific subcapacities.

Wickens et al. (1981) found two specific task sharing factors. One was concerned with the visual-spatial tasks paired together; the second involved auditory memory task combinations. The former factor seems to be defined by visual acuity demands. The latter may be related to the ability to switch between auditory and visual modes, but this factor may also be interpreted as a capacity of short-term memory, such that time-sharing the second task with the auditory memory task is facilitated. Gopher and North (1977) found that over a period of time, performance on a tracking task improved in single task presentation as well as in the dual task, while digit processing improved only in the dual task condition. This finding suggests again that certain tasks are more amenable to time-sharing than others.

On the other hand, Damos and Wickens (1980) uncovered a time-sharing factor they considered to be general, and in addition, demonstrated transfer between dual-tasks, which were quite dissimilar in terms of inputs, response selection, and execution. The finding of significant transfer supports the notion of a generalized skill or strategy. Damos (1978) and Damos and Smist (1980) noted that subjects quickly adopted different response strategies in dual-tasks (i.e., simultaneous, alternating, or massed strategies) and would generally not shift their strategies, even when requested to do so. On the other hand, Alluisi and Morgan (1971) discovered that on certain combinations of subtasks subjects would employ different response strategies. These variations depended upon the specific pairings of task types, and the degree of work load stress imposed.

Finally, Keele, Neill, and deLemos (1978) provided some evidence for a divided attention ability. They indicated that the degree of relationship between different types of attention switching tasks was moderate, with only 6 of 15 correlations being significant.

A different aspect of the time-sharing factor is related to the differences in people to adjust their performances in complex task situations. North and Gopher (1976) and Gopher and Kahneman (1971) found large differences among individuals in their ability to allocate attention as demanded by changes in task priorities. This 'attention manageability' was found to be predictive of performance in flight training (Damos, 1978). A subject may be able to perform the dual-task at a certain level but be unable or lack the flexibility to divert resources from one subtask to another. This observation may underscore

a dependence on a specific mode of sharing the common resources (Navon & Gopher, 1979). Hunt et al.'s (1979) findings partially indicated that subjects were not able to allocate their attention as instructed; and suggested that task characteristics, as well as subject strategies, can influence the allocation of attention. Other investigators have, on the contrary, reported subjects being able to adjust relative task performances in a graded, continuous fashion (Wickens & Gopher, 1977).

One piece of evidence suggests that an adequate test for a general time-sharing ability may not have been made. Damos, Bittner, Kennedy, and Harbeson (1981) have shown that dual critical tracking does not become differentially stable until after very extended practice. Differential stability would require high and stable test-retest correlations, and would indicate stable rank orderings of subjects over repeated testings. Such a stable relative ordering would be required to identify a general time-sharing factor. No studies investigating time-sharing have looked at the differential stability of the tasks used.

EFFECTS OF ENVIRONMENTAL STRESSORS ON COMPLEX PERFORMANCE

A cross-section of environmental conditions were included in a recent review of multiple-test systems employed by USAFSAM to assess performance (Hartman, Benel, and Storm, 1979). Primarily included as environment variables were alterations of altitude, air pressure and atmosphere composition, with a few other types. The test batteries included tasks from flight simulators which were typically more complex than the dual-tasks discussed in this paper, and the work schedules were often longitudinal, up to 56 days. Of these 21 studies, seven found no overall decrements in performance, while a majority of the studies did find some decrement among one or more of the variables. However, conclusive statements about any particular environmental factor are difficult to draw; no single factor or condition within the parameters used could be said to be prepotent.

Bateman (1980) examined performance decrements on dual-tasks as a function of ambient temperature and found significant decrements due to increased temperature on relatively simple tasks, such as vigilance, reaction time and Stroop tests. For complex tasks, performance remained generally effected or improved, though there were indications of a trend for some decrements at the highest temperature. The explanation of this somewhat paradoxical finding was in terms of arousal and capacity. The ambient temperatures used changed arousal by slightly raising the body core temperature. For simple tasks this had the effect of reducing performance. On complex tests, the tasks themselves were apparently stimulating enough to nullify the effect of the temperature.

Certain cues provide information to the operator either that a threatening event is approaching spatially or temporally, or that a change has occurred in the probability of its occurrence. Such attributions have been found to affect the performance characteristics of the operator (Curran & Wherry, 1967; Wherry, 1966). Performance decrements on complex tasks seems to be associated with (a) perceived time since the situation started, (b) perceived time until the undesirable event occurs, and (c) perceived time elapsed since the initial warning. There seem to be large individual differences in the performance effects associated with psychological stress. These findings might be used in test battery

development by implementing some type of time stress that is associated with an outcome.

IMPLICATIONS FOR THE DEVELOPMENT OF A GENERIC WORK STATION

1) Given the advantage of using the different modes of input and output over using the same modes, it follows that operator performance in a work station would be relatively enhanced if inputs (to the operator) and responses are distributed over different sensory modalities. For example, instead of having two information sources which are both visual, one might be transfered to an auditory mode. Likewise, output channels could be spread over manual and verbal modes instead of stacking responses in one mode. The little evidence available suggests proprioceptive information can be used as a complementary source to other modes in enchancing control performance.

2) The literature on brain hemispheric lateralization suggests that less interference between responses for various subtasks will occur when the response systems are functionally and structurally less related. Therefore, diagonal pairings are more efficient than ipsilateral and ipsilateral response systems are superior to mirror-image paired limbs (e.g., hands).

The fact that interactions with the type of material can occur (i.e., processing of semantic vs. acoustic properties of visual stimuli, Rollins and Hendrick, 1980), suggests that the careful selection and control of the type of information carried by a particular mode may be useful. For example, when information is being presented simultaneously in two modes, the visual input could handle semantic, but not acoustic, analysis.

Interference between subtasks can be expected to the degree that the resources required draw on the same functional hemispheric space. Functionally verbal/analytic subtasks are primarily left-hemispheric dominant while spatial/visual/holistic are right-hemispheric dominant. It would seem appropriate to plan for the sharing of subtasks within any given time period that were unlike in terms of functional lateralization of the demands on their resourses. A task requiring identification of spatial characteristics would be shared better with a verbal processing task, than either of those tasks shared with a task similar to itself. Therefore, the information source for a particular task should be received by the perceptual pathways and hemisphere that is optimal for the processing of that particular type of information. Thus, an idealized example would be a task pair with both spatial and verbal/analytic subtasks. The optimal display configuration would present the spatial information to the left visual field (right hemisphere) and have the control response executed by the left-hand side, and the verbal/analytic information would be presented to the right visual field (left hemisphere) and utilize the right-hand side for response. Optimal performance regarding these factors can be expected when the information type, perceptual pathway and hemisphere, and response system are all functionally congruous.

3) The demand composition of subtasks in terms of the overlap in the stages of processing determines to a large degree the amount of interference between subtasks. Two subtasks loading on the same stages of processing will show relatively more dual-task decrement than if the subtasks load primarily on different stages. Therefore, the analysis of subtasks in the generic work

station is important in predicting which tasks can be co-performed successfully. Points of specific interest regarding stages of processing follow.

4) There is less interference among tasks which are complementary in that one requires perceptual encoding while the other requires central processing. The literature suggests these two groupings of task types may require somewhat independent reservoirs of resources. This idea further suggests that the pairing of tasks within any given time period should be different in demand compositions.

5) A specific example of the above concerns short-term memory demands which are generally found to be disruptive of dual-task performance. This disruption can occur even in the case where, for either tracking or reaction time paradigms, only one subtask has short term memory requirements. In an ongoing complex performance situation, a useful approach might be to build into the system a mechanism that allows the operator to close the temporal span between operator reception and processing of information. This could be done by reducing the operators short term memory load by building in some manner of 'hold' on low priority information, until the operator can process the input. If short term memory demands on the operator can be decreased, performance on all subtasks should improve.

6) Subtasks that share central processing may or may not interfere, depending on the specific nature of the subtasks. A priori predictions are difficult as there are few taxonomies of transformations or models of central processing that are adequately discriminating or comprehensive. In terms of the tracking paradigm, central processing tasks that can be successfully shared include cognitive and verbal activity, such as mental calculations and shadowing. Thus, a response loaded activity such as tracking can be effectively shared with many transformation tasks. This is quite unlike the reaction time paradigm, however, for which difficulty maniuplations of difficulty show considerable task-performance tradeoff with mental computation type tasks (Keele, 1967).

The effect of pairing encoding and tracking depends on which subtask receives manipulations of the difficulty variable. Changes in tracking difficulty do not affect encoding performance, whereas changes in encoding difficulty do influence tracking performance. The import of this phenomenon is that an upper limit of task difficulty may be necessary in order to control performance decrements. When that level is reached, subtasks could be delayed or shifted to other operators.

7) The results regarding time-sharing as an ability are equivocal, but enough commonality can be found to indicate some tentative implications for a generic workstation. A number of investigators have found similar task specific time-sharing factors, such as monitoring or attention switching between heterogeneous tasks. These findings have indicated the possibility of constructing specific sub-tasks in conjunction with others to maximize any time-sharing that could develop. At this point, the most promising example is probably the pairing of active tasks (e.g., computational) with monitoring tasks, or tasks which allow some automation of processes.

The attribute of attention-switching, dividing, or manageability is related to time-sharing. This construct has been found to be correlated with a number of types of complex performance. This suggests that future performance test development may benefit from employing one or more complex tests which require the shifting of attention between subtasks.

8) Certain environmental conditions, which are assumed to be stressors or attributions about impending environmental conditions, may affect dual-task performance in unexpected ways. Interactions may result between the environmental variables and task difficulty (Bateman, 1980). In addition, response, styles may change with the nature of the subtasks (Alluisi & Morgan, 1971). An important question is whether such response style changes are to a relatively more adaptive and efficient style, or simply to a more comfortable one in the face of increasing demands. There is little evidence to shed light on this issue. Likewise, the resistance of certain task combinations to performance decrements when shared is credited to dependence on separate resource reservoirs. But it has also been suggested that under large demands on one pool, resources from another can be transfered and applied to the demanding task. It may be that as task difficulty increases, the advantage of pairing tasks relying on separate structures will decrease.

The major findings in terms of the primary paradigms used in dual-task analysis as they relate to a generic workstation can be summarized under two paradigms: a) a tracking task (as a continuous task) is paried with another task, generally discrete, and b) a reaction time task is used with a tracking, reaction time, computation, or short term memory task (see Wickens, 1980 for a summary). As mentioned earlier, when tracking is paired with encoding tasks, encoding will not generally be affected by alterations in tracking, but when encoding is varied, tracking performance is found to decrease. When tracking is manipulated with reaction time tasks, performance on the latter does decrease (Isreal, Wickens, & Donchin, 1979). However, when the reaction time task is the independent variable, the mode of input seems to be important in demonstrating an effect. As suggested earlier, visual reaction time tasks disrupt tracking performance, while reaction time tasks using auditory input generally do not affect tracking performance. In addition, the manipulation of certain central processing tasks, such as mental computation, appears to have no effect on tracking performance. When memory tasks are paired with tracking, interference generally results, regardless of which task is manipulated.

As with tracking tasks, memory tasks paired with reaction time tasks do reliably reduce performance on the reaction time task. When two reaction time tasks are paired together high interference is generally seen, and this would be predicted from information presented earlier, since there is going to be a large (and perhaps exact) overlap in terms of central processing demands required. Tracking tasks, paired with themselves, show a similar large tradeoff due to the overlaying of similar demand compositions.

In summary, the recommendations for generic workstation design are: 1) distribute operator inputs over various sensory modalities, and outputs over various effectors; 2) make simultaneous responses as unrelated as possible in terms of anatomical structure and mental function; 3) avoid overlapping loads in terms of stages of mental processing; 4) utilize simultaneous perceptual

encoding and central processing, as these represent independent resource pools; 5) avoid overloading short-term memory during multiple-task performance; 6) investigate possible interference among central processing tasks prior to combining them; 7) the ability to switch attention among tasks may vary among individuals, and should be considered in workstation design; and 8) human performance at multiple-task workstations will be affected in different ways by different environmental contexts - the nature of the performance decrement deserves as much research attention as the magnitude of an environment-induced decrement.

Table 1: Summary of Dual-Task Findings

Citation	Method	Results
Allport, Antonis & Reynolds, 1972	1) Auditory shadowing task with memorization of words or pictorial material. 2) Auditory prose shadowing & piano playing from a score.	Subjects can repeat back speech while memorizing complex unrelated visual scenes or while sight reading music. Little effect of co-task on accuracy of speech shadowing.
Alluisi & Morgan, 1971	5 combinations of MTPB tasks paired with a 3-phase code transformation task.	Effects on some task combinations. Ss choose different response strategies for different conditions
Bateman, 1980	Tracking task combined with one of six secondary tasks under 3 different ambient temperatures.	Found decreased performance on simple secondary tasks but not on complex secondary tasks.
Briggs, 1975	Complex Coordinator requiring multiple limb responses to light array: paired with an auditory task.	Right hand made more errors in verbal condition.
Briggs, Peters & Fisher, 1972	Tracking with choice RT, with different response set sizes, and levels of accuracy demand.	RT's increased with tracking. No effect of number of response alternatives on tracking. Effect on RT localized in encoding stage.
Brooks, 1968	Memory task with either verbal or spatial imput and verbal or spatial response mode.	Verbal recall was disrupted by concurrent vocal activity, while recall of spatial material was disrupted by spatially monitored responses.

Curran & Wherry, 1967	Simulated flight over hostile territory to examine factors in perceived threat.	Performance correlates with (a) closeness in time of event, (b) probability of events occurance, (c) increase in perception of unpleasantness of event. Large individual differences found in susceptibility to performance decrements.
Damos, 1978	Groups based on self-selected response strategies.	Alternating group strategy superior on dual tracking, but poorer on dichotic listening than simultaneous group strategy. Implications to lateralization differences among groups.
Damos, Bittner, Kennedy & Harbeson, 1981	Dual critical tracking	Differential stability not achieved until 10 sessions for already practiced subjects.
Damos & Smist, 1980	3 Task combinations: memory/ classification, dual 1-dimensional tracking, and dichotic listening task. Ss self-select into response style groups.	Trials and groups significant. Group differences associated with differences in lateralization.
Damos & Wickens, 1977	Tracking task paired with choice RT task. Displays were either separate or adjacent.	Tracking performance declined as information load in RT task increased.
Damos & Wickens, 1980	Task pairs of STM with classification and dual-tracking. Groups varied in what tasks (single and paired) they received training on.	Found time-sharing for both combinations. Evidence for transfer of time-sharing in in form of parallel processing.
Daneman & Carpenter, 1980	Memory and verbal processing tasks integrated into one task, by retaining a part of a passage read for comprehension.	Found high correlation between accuracy of recall & reading ability, suggesting reading ability is a function of combining memory and verbal processing.
Gopher & Kahneman, 1971	Dichotic listening for relevant messages to one side vs irrelevant to the other.	No. of omissions as error measure predicted flight training intrusions of incorrect responses did not predict flight criteria.

Table 1 continued

Gopher & North, 1977	Tracking paired with digit-processing RT task under (a) different desired levels of performance (b) training with equal and unequal priorities and (c) repeated sequencing of single and dual task conditions.	a) Found tracking was more sensitive to priority changes than digit processing. b) Tracking performance improved during repeated single task conditions while digit processing improved during dual-task conditions.
Harris, Owens, & North, 1978	Tracking paired with continuous digit subtraction, with vocal or keyboard response.	Tracking affected one measure of processing (error density). Less error in vocal mode than keyboard even with practice on the latter.
Hawkins, Rodriquez, & Reicher, 1979	Varied response mode (vocal vs manual) and stimulus mode (auditory vs visual) on RT task 1 and difficulty on RT task 2.	Time-sharing efficiency only across tasks which share similar processing demands. No general time-sharing factor.
Hellige & Cox, 1976	Short term memory task while doing recognition of visual stimuli presented to either right or left visual field. Stimuli were either verbal or spatial.	Improved recognition of visio-spatial stimuli with low memory load compared to no load. For right visual field, high memory load decreased. Similar findings for verbal stimuli but for both visual fields.
Henderson, 1975	Unscramble visually presented words to form a sentence with sentence shadowing with differences in rate or amt. of silent periods.	Verbal output seems to decrease cognitive performance.
Hunt, Lansman & Wright, 1979	a) Priority on complex reasoning task while performing a constant physical pressure task. (b) Auditory comprehension paired with either the pressure task or a more difficult target shooting task.	a) Performance on secondary task was predictive of later performance on more difficult form of the primary task. (b) There was decrement on primary rather than secondary task.
Isreal, Chesney, Wickens, & Donchin, 1980	a) Tracking task paired with task of counting tones. (b) Tracking paired with RT task.	No effect of counting on tracking. Tracking increased response latency and proportion of errors on RT.

Table 1 continued

Isreal, Wickens, & Donchin, 1979	Tracking or display monitoring paired with reaction time.	Tracking difficulty increases RT.
Jennings & Chiles, 1977	2 complex tasks of 3 subtasks each from Multiple Test Performance Battery with training on single tasks.	Found factor related to ability to shift attention quickly from active to monitoring tasks.
Johnston, Greenberg, Fisher, & Martin, 1970	Tracking paired with different verbal tasks to differentially load on word encoding, retention or recall.	All stages of verbal processing conditions affected by dual-task conditions. Recall most disrupted. Tracking error was a direct function of difficulty of verbal processing in all experiments.
Kantowitz & Knight, 1976	Paced tapping task paired with auditory digit-naming task, with either a verbal or manual response.	Interaction between tasks for manual response condition, no interference in verbal response condition.
Keele, 1967	Serial RT task shared wth a mental computation task. Varied stimulus-response compatibility.	Reaction times increased as the difficulties of the computation task increased. The secondary task had greater effect the less S-R compatability there was.
Keele, Neill, & deLemos, 1978	4 types of tasks involving processing of signals under different conditions of set, and expectancy.	Found individual difference factor based on attentional flexibility. Moderate correlations across different tasks.
Kinsbourne & Hicks, 1978	Review includes a variety of paradigms.	Interference between limbs decreases from mirror-image to ipsilateral to diagonal pairings. More interference in vocal-manual with voice & right hand than left. Decrement with both hands for left-handers. Perceptual interference with various stimuli types.
Lansman, 1978	Paired short-term memory and verbal ability/grammatical reasoning. Type task to predict general verbal ability.	Single and dual task performance predicted verbal ability equally well.

Table 1 continued

Lansman & Hunt, 1981	1) Visual and auditory detec- in single channel focused attention, and divided attention conditions. (2) Easy serial learning task with simple RT.	1) Single channel condition highly predicted and divided attention conditions. (2) Secondary task performance predicted per- on a difficult level of primary task.
Logan, 1978	1) Short term memory task performed with a character classification task. (2) Memory task shared with various stages of visual search task.	1) Found interactions between memory load and target set size. (2) Memory load affected only comparison stage and not encoding, decision, and response selection.
Long, 1976	Choice reaction time tasks presented singly or in pairs. Varied frequency and intensity of signals as difficulty manipulation.	Significant decrease on 2nd task with increase in difficulty on 1st, for data over two experiments combined.
McLeod, 1977	1) Manual tracking paired with two-choice tone identification, with either vocal or manual response. (2) Tracking with mental arithmetic.	1) Found performance decrements when tone responses were manual. (2) Tracking performance was independent of mental arithmetic difficulty.
North, 1977	Single and paired tasks of tracking, immediate digit cancellation, delayed digit cancellation, and classification of digits.	Pairs dissimilar in demands on processing stages were better performed than pairs similar in such demands. Short term memory demands on either/both tasks was highly disruptive.
North & Gopher, 1976	Digit processing RT task shared with a tracking under equal and shifting priorities.	Found individual differences in subjects ability to allocate attention with changes in task priorities as well as the ability to cope with timesharing conditions. These factors correlated with success in flight training.
Ostry, Moray & Marks, 1976	1) Detect letters in a stream of auditorily presented digits under dichotic conditions. 2) Detect animal names embedded in a string of nouns. Presented under selective or divided attention.	Attention condition affects detect ability and response criteris: Interference occurred between the two channels.

Table 1 continued

Rollins & Hendricks, 1980	Concurrent processing of auditory & visual input in a target detection task.	Processing of semantic but not acoustic word properties is independent between visual & auditory systems.
Schulman & Greenberg, 1971	1) Comparitive judgment task paired with short-term memory. 2) Perceptual recognition task paired with short-term memory.	Decrements in both cases as a function of increasing memory load.
Sverko, 1977	Task pairs from rotary pursuit, mental computation, digit processing, and auditory discrimination.	Factor analysis on single and paired task score inter-intercorrelations revealed no general time-sharing factor.
Teng, 1980	Pairing of input types; tone-tone, digit-digit, or digit-tone balanced for channels.	Performance better for different inputs than same. Right ear advantage for digits & left ear advantage for tones when input the same. No ear advantage for mixed inputs averaged over ears.
Trumbo & Milone, 1971	Tracking paired with encoding, retaining and/or recalling of a serial learning task.	Recall caused most decrement in tracking, followed by encoding and least by retaining. No cummulative effect of overlapping on 2 stages of learning. Tracking did not interfer with learning.
Wickens, 1976	Tracking paired with input task (auditory signal detection) or output task (constant manual force).	More decrement in output shared condition.
Wickens, 1980	Tracking with digit subtraction: varied difficulty across all stages and shared either 0,1, or 2 modes of encoding & responding.	Better performance using separate vs same modes. Difficulty performance trade-offs not affected by number of shared modalities.
Zeitlin & Finkelman, 1975	Tracking paired with random digit generation of digit recall under three levels of load.	Delcared digit recall did differentiate among load conditions while digit generation did not. No effect of either subsidiary task on tracking.

REFERENCES

Allport, D., Antonis, B., & Reynolds, P. On the division of attention: A disproof of the single channel hypothesis. Quarterly Journal of Experimental Psychology, 1972, 24, 225-235.

Alluisi, E., & Morgan, B. Effects on sustained performance of time-sharing a three-phase code transformation task (3P-COTRAN). Perceptual and Motor Skills, 1971, 33, 639-651.

Bateman, R. P. The effects of increased ambient temperature on dual-task performance. Unpublished doctoral dissertation, Texas A & M University, December 1980.

Briggs, G. G. A comparison of attentional and control shift models of the performance of concurrent tasks. Acta Psychologia, 1975, 39 183-191.

Briggs, G., Peters, G., & Fisher, R. On the locus of divided attention effects. Perception and Psychophysics, 1972, 11, 315-320.

Brooks, L. R. Spatial and verbal components of the act of recall. Canadian Journal of Psychology, 1968, 22, 349-368.

Curran, P., & Wherry, R. Some secondary determiners of psychological stress. Aerospace Medicine, 1967, 38, 278-281.

Damos, D. Residual attention as a predictor of pilot performance. Human Factors, 1978, 20, 435-440.

Damos, D., Bittner, A. C., Jr., Kennedy, R. S., & Harbeson, M. M. Effects of extended practice on dual-task performance. Human Factors, 1981, 23, 627-631.

Damos, D., & Smist, T. Individual differences in dual-task performance. (NBDL Monograph NBDL-M006) New Orleans, LA: Naval Biodynamics Laboratory, November 1980. (AD-A099977)

Damos, D., & Wickens, C. Dual-task performance and Hick's Law. Journal of Motor Behavior, 1977, 9, 209-215.

Damos, D. & Wickens, C. The identification and transfer of time-sharing skills. Acta Psychologia, 1980, 46, 15-39.

Gopher, D., & Kahneman, D. Individual differences in attention and the prediction of flight criteria. Perceptual and Motor Skills, 1971, 33, 1335-1342.

Gopher, D., & North, R. Manipulating the conditions of training in time-sharing performance. Human Factors, 1977, 19, 583-594.

Harris, S., Owens, J., & North, R. A system for the assessment of human performance in concurrent verbal and manual control tasks. Behavior Research Methods and Instrumentation, 1978, 10, 329-333.

Hartman, B., Benel, R., & Storm, W. A review of USAFSAM studies employing multiple-task performance devices. Brooks AFB, TX: USAF School of Aerospace Medicine, 1979.

Hawkins, H., Rodriguez, E., & Reicher, G. Is time-sharing a general capability? Proceedings of the 23rd Annual Meeting of the Human Factors Society, 1979, 532-535.

Hellige, J., & Cox, P. Effects of concurrent verbal memory on recognition of stimuli from the left and right visual fields. Journal of Experimental Psychology: Human Perception and Performance, 1976, 2, 210-221.

Henderson, A. A note on the interference between verbal output and a cognitive task. Acta Psychologia, 1975, 39, 495-497.

Hunt, E., Lansman, M., & Wright, J. Some remarks on doing two things at once. (ONR Technical Report) Seattle: University of Washington, April 1979.

Isreal, J., Chesney, G., Wickens, C., & Donchin, E. P-300 and tracking difficulty: Evidence for a multiple capacity view of attention. Psychophysiology, 1980, 17, 259-273.

Isreal, J., Wickens, C., & Donchin, E. The event-related brain potential as a selective index of display mode. Proceedings of the Human Factors Society, 1979, 558-562.

Jennings, A., & Chiles, W. An investigation of time-sharing ability as a factor in complex performance. Human Factors, 1977, 19, 535-548.

Johnston, W., Greenberg, S., Fisher, K, & Martin, D. Divided attention: a vehicle for monitoring memory processes. Journal of Experimental Psychology, 1970, 83, 164-171.

Kantowitz, B. A., & Knight, J. Testing, tapping and time-sharing II: Use of auditory secondary task. Acta Psychologia, 1976, 40, 343-362.

Katz, A. Cognitive arithmetic: Evidence for right hemispheric mediation in an elementory component stage. Quarterly Journal of Experimental Psychology, 1980, 32, 69-84.

Keele, S. Compatibility an time-sharing in serial reaction time. Journal of Experimental Psychology, 1967, 75, 529-539.

Keele, S., Neill, W., & deLemos, S. Individual differences in attentional flexibility. (Tech Rep. No. 1) Eugene: University of Oregon Center for Cognitive & Perceptual Research, 1978.

Kerr, B. Processing demands during mental operations. Memory and Cognition, 1973, 7, 401-412.

Kimura, D. Spatial localization in the left and right visual field. Canadian Journal of Psychology, 1969, 23, 445-458.

Kinsbourne, M. The mechanism of hemispheric control of the lateral gradiant of attentions. In P. Rabbitt and S. Dornic (Eds.) Attention and Performance V, London: Academic Press, 1975.

Kinsbourne, M., & Hicks, R. Functional cerebral space. In J. Requin (Ed.) Attention and Performance VII, Hillsdale, N. J.: Erlbaum, 1978.

Lansman, M. An attentional approach to individual differences in immediate memory. (Tech. Rep. No. 2) Seattle: University of Washington, 1978.

Lansman, M., & Hunt, E. Individual differences in dual-task performance. (ONR Final Report) Seattle: University of Washington, June 1981.

Logan, G. Attention in character-classification tasks: Evidence for the automaticity of component stages. Journal of Experimental Psychology, 1978, 107, 32-63.

Long, J. Effect of task difficulty on the division of attention between non-verbal signals: Independence or interaction. Quarterly Journal of Experimental Psychology, 1976, 28, 179-192.

Marguardt, L., & McCormick, E. Attribute ratings and profiles of the job elements of the Position Analysis Questionnaire (PAQ). (Tech. Rep TR-1) W. Lafayette, IN: Purdue University, 1972.

McCormick, E., Jeanneret, P., & Mecham, R. A study of the job characteristics and job dimensions as based on the Position Analysis Questionnaire. Journal of Applied Psychology Monograph, 1972, 56, 347-368.

McLeod, P. A dual-task response modality effect: Support for multiprocessor models of attention. Quarterly Journal of Experimental Psychology, 1977, 29, 651-667.

Navon, D., & Gopher, D. On the economy of the human-processing system. Psychological Review, 1979, 86, 214-255.

Norman, D., & Bobrow, D. On data-limited and resource-limited processes. Cognitive Psychology, 1975, 7, 44-64.

North, R. Task functional demands as factors in dual-task performance. Proceedings of the 21st Annual Meeting of the Human Factors Society, San Francisco, 1977, 367-371.

North, R., & Gopher, D. Measures of attention as predictors of flight performance. Human Factors, 1976, 18, 1-9.

Ostry, B., Moray, W., & Marks, G. Attention, practice, and semantic targets. Journal of Experimental Psychology: Human Perception and Performance, 1976, 2, 326-336.

Pomerantz, J., Sager L., & Stoever, R. Perception of wholes and of their component parts: Some configural superiority effects. Journal of Experimental Psychology: Human Perception and Performance, 1977, 3, 422-437.

Rollins, H., & Hendricks, R. Processing of words presented simultaneously to eye and ear. Journal of Experimental Psychology: Human Perception and Performance, 1980, 6, 99-109.

Shaffer, L. Multiple attention in continuous tasks. In P. M. Rabbitt & S. Dornic Eds.) Attention and Performance V, London: Academic Press, 1975.

Shulman. H. G., & Greenberg, S. N. Perceptual deficit due to division of attention between perception and memory. Journal of Experimental Psychology, 1971, 88, 171-176.

Sverko, B. Individual differences in time-sharing performance. (Aviation Research Laboratory Technical Report ARL-77-4/AFOSR-77-4) Urbana-Champaign: University of Illinois, January 1977.

Teng, E. L. Dichotic pairing of digits with tones: High performance level and lack of ear effect. Quarterly Journal of Experimental Psychology,

Treisman, A., & Davies, A. Divided attention to eye and ear. In S. Kornblum (Ed.) Attention and Performance IV, London: Academic Press, 1973.

Trumbo, J., & Milone F. Primary task performance as a function of encoding, retention, and recall in a secondary task. Journal of Experimental Psychology, 1971, 91, 273-279.

Welford, A. Mental workload as a funcion of demand, capacity, strategy, and skill. Ergonomics, 1978, 21, 151-167.

Wherry, R. Model for the study of psychological stress. Aerospace Medicine, 1966, 37, 495-500.

Wickens, C. The effects of divided attention on information processing in tracking. Journal of Experimental Psychology: Human Perception and Performance, 1976, 1, 1-13.

Wickens, C. The structure of attentional resources. R. Nickerson (Ed.) Attention and Performance VIII. Hillsdale, N. J.: Erlbaum, 1980.

Wickens, C., & Gopher, D. Control theory measures of tracking as indices of attention allocation strategies. Human Factors, 1977, 19, 349-366.

Wickens, C., & Kessle, C. The effect of participatory mode and task workload on the detection of dynamic system failure. IEEE Transaction on Systems, Man and Cybernetics, 1979, 13, 21-31.

Wickens, C., & Kessel, C. The processing resource demands of failure-detection in dynamic systems. Journal of Experimental Psychology: Human Perception and Performance, 1980, 6, 564-577.

Wickens, C., Mountford, S., & Schreiner, W. Multiple resources, task-hemispheric integrity, and individual differences in time sharing. Human Factors, 1981, 23, 211-230.

Zeitlin, L., & Finkelman, J. Subsidiary task techniques of digit generation and digit recall as measures of operator loading. Human Factors, 1975, 17, 218-220.